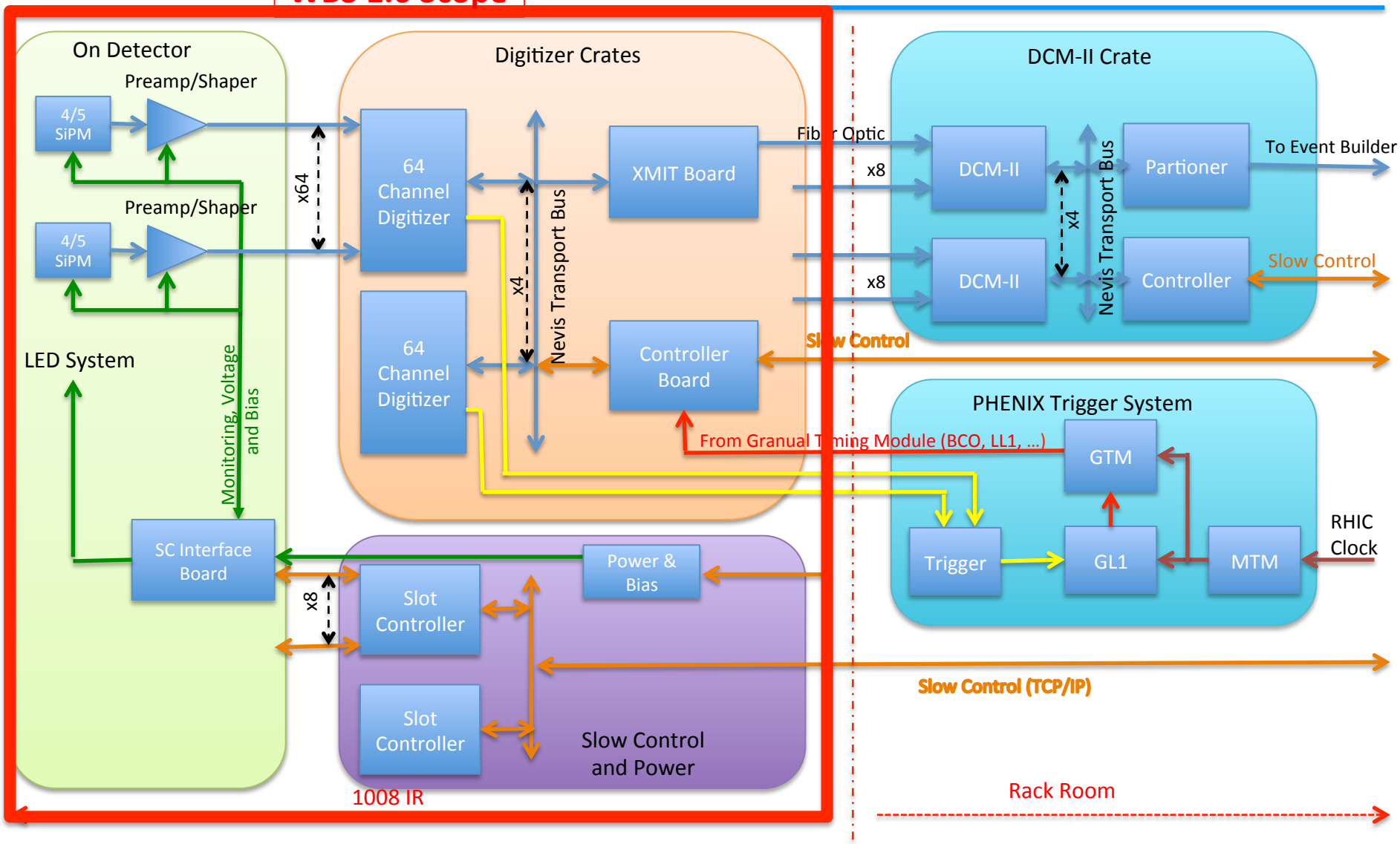
WBS 1.6
Calorimeter Electronics

E.J. Mannel

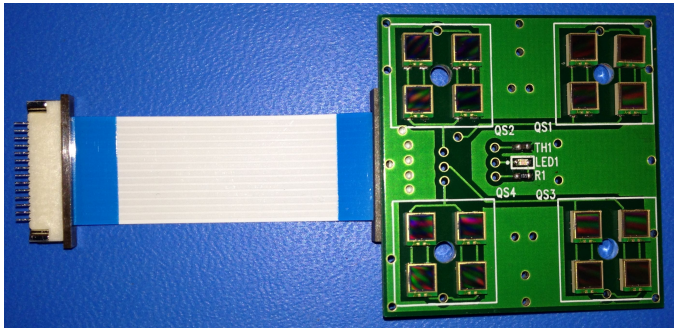
29-Nov-2016

Calorimeter Electronics Overview-I

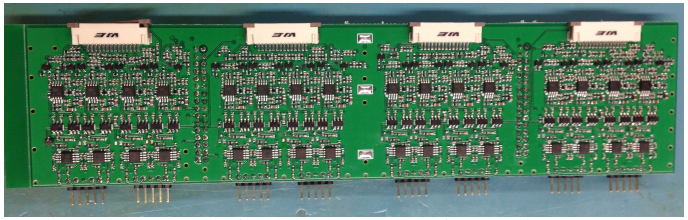


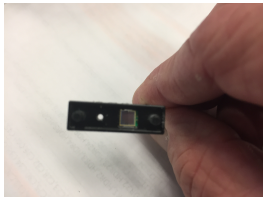
System Overview - II

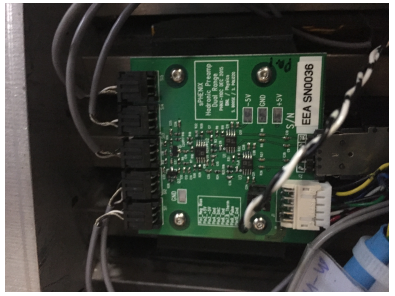
- "Common" Design for both EMCal and HCal
  - Optical sensor: Silicon Photomultiplier (SiPM)
  - Font end analog section:
    - Amplification
    - Shaping
    - Gain adjust
    - Different packaging for EMCal and HCal.
    - Located on detector
  - Digital backend section:
    - Continuous waveform digitization
    - 14 Bit ADC
    - 6x Beam Clock digitization rate
    - Located near detector in IR
  - Common low voltage and bias voltage systems



EMCal SiPM daughterboard for 4 towers


EMCal 2x8 Preamp board

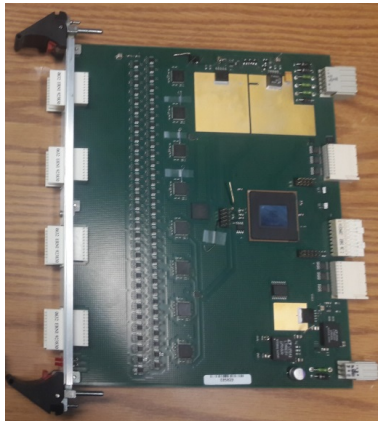


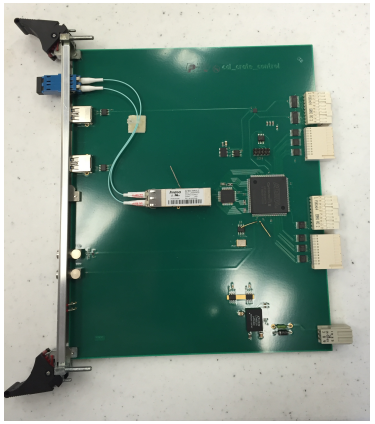


Hcal SiPM holder and Preamp board

WBS 1.6: Design Drivers

- Optical Sensors:
  - Immune to magnetic fields
  - Dynamic Range: 10^4
  - Gain: 10^5
  - Photon Detection Efficiency: 25%
- Analog Front End:
  - Signal-to-Noise: 10:1
  - Peaking time: 30 nSec
  - Gain: 100 mV/pC
- Digitizer:
  - Resolution 14 bits (12 bit effective)
  - Maximum sampling frequency: 65 MHz
  - Latency (L1 Trigger): 40 Beam Crossings (BCO)
  - Multi-event buffering: 4 Events
  - L1 Trigger rate: 15 KHz





Digitizer Board (left) and Crate Controller (Right)

Prototype Crate with XMIT, Digitzer and Controller boards

WBS 1.6 Scope

- Optical Sensors:
  - EMCal: 98304 SiPMs
  - HCal: 13824 SiPMs
- Front End Analog Electronics:
  - Amplifier/Shaper/Driver Circuits for
    - EMCal: 24576 Channels
    - Hcal: 3027 Channels
  - Front End Slow Control:
    - EMCal: 64 Channels
    - HCal: 128 Channels
    - Crates: 8
  - LED Based Testing/Calibration System
    - EMCal: 6144 channels
    - HCal: 128 Channels
- Back End Digital Electronics:
  - ADC Boards: 432
  - XMIT Boards: 108
  - Controllers: 28
  - Clock Masters: 28
  - Crates: 28
- Power & Cabling:
  - Power Supplies: TBD
  - Power Cables: TBD
  - Analog Signal Cables: 1728
  - Optical Signal Cables: 164
  - Slow Control Cables: 192
- Q/A Testing and Reviews At All Stages

WBS 1.6: Interfaces

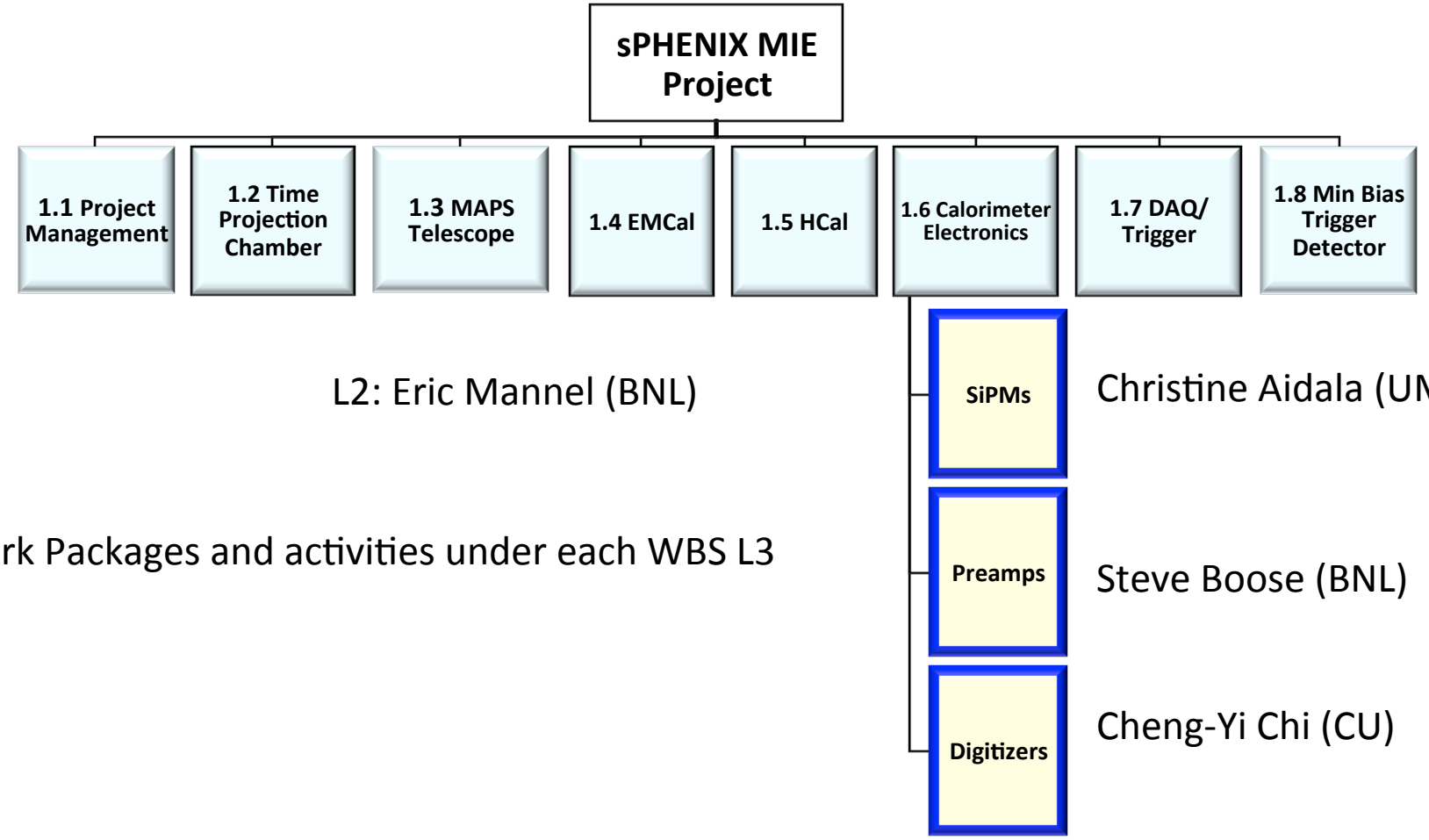
Inside the scope of WBS 1.6:

- Optical sensors
  - HCal SiPM boards w/ SiPMs
  - EMCal SiPM boards w/ SiPMs
- Analog Electronics
  - Amplifiers (EMCal/HCal)
  - Controls (EMCal/HCal)
  - On board electronics cooling (EMCal)
  - LED Calibration (EMCal/HCal)
  - Crates & power supplies (EMCal/HCal)
  - Internal signal cables (EMCal/HCal)
- Digital Electronics
  - Digitzer Modules
  - Controllers/XMIT modules
  - Crates & power supplies
  - Analog signal cables
  - Optical cables to IR Patch cables

Outside the scope of WBS 1.6

- DAQ
  - Bulk Optical Cable (WBS 1.10)
  - DCM-IIs (WBS 1.7)
- Trigger & Timing (WBS 1.7)
- Electronics Cooling System (WBS 1.10)
- Racks (WBS 1.10)
  - AC Power
  - Smoke/Water detectors
  - Rack Cooling
- Installation
  - EMCal Front End (WBS 1.4)
  - HCal Front End (WBS 1.5)
  - Digitzer Crates (WBS 1.11)
  - External Cable routing (WBS 1.11)

WBS 1.6: Management Structure

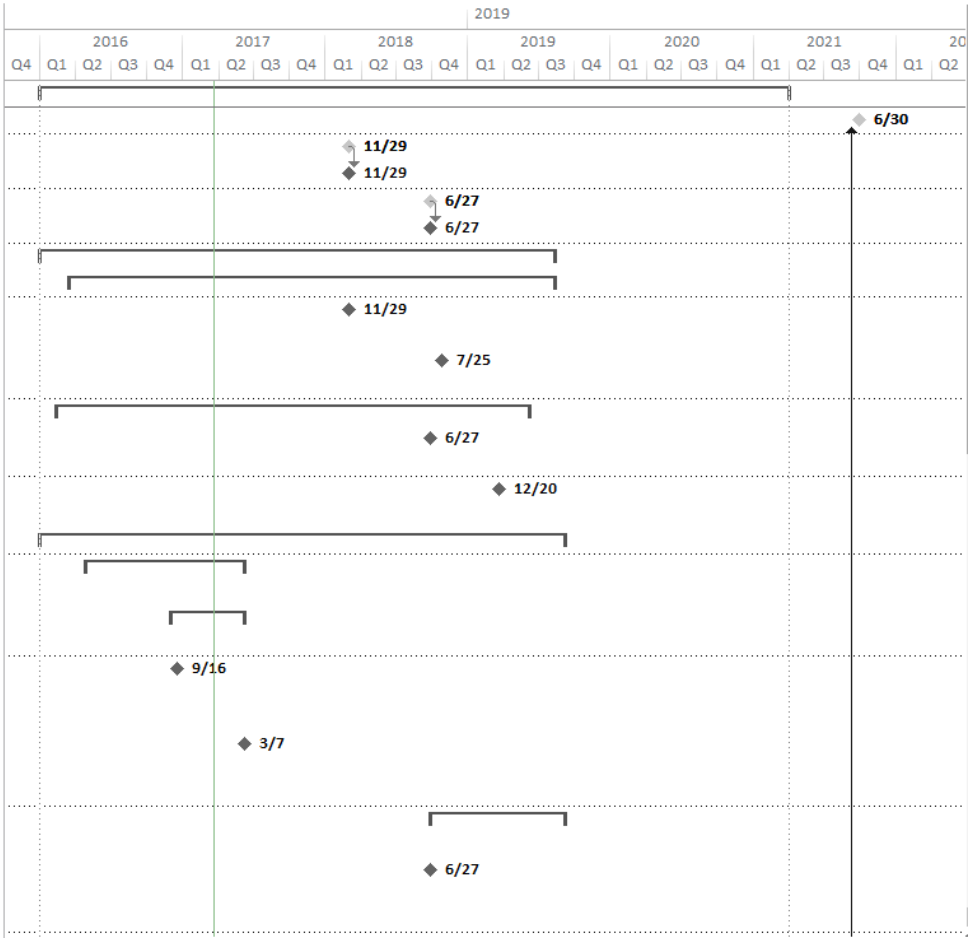


WBS 1.6: L2 Manager and CAMS

- Eric Mannel (BNL)- L2
  - HiRes Fly's Eye:
    - Hardware/Software Integration
    - Calibration Systems
    - DAQ Design
  - VTX Electronics Project Engineer
    - Project management
    - Power Systems Design
  - FVTX Electronics Project Engineer
    - Project management
    - Power Systems Design
- Christine Aidala (UM)- CAM SiPMs
  - Associate Professor
  - Co-Convener sPHENIX Cold QCD Topical Group
  - Member of the sPHENIX IB
  - Hardware experience on PHENIX FVTX detector
    - Detector assembly
    - Q/A Procedures
- Steve Boose (BNL)- CAM Analog Electronics
  - Senior Electrical Engineer
  - 39 years of experience
  - Developed ocean and atmospheric sensor hardware/software in support of DOE Ocean Margins and NASA Sea-Wifs programs
  - Analog, Digital and Power System design for PHENIX/sPHENIX
- Cheng-Yi Chi (CU/Nevis Labs)- CAM Digital Electronics
  - Senior Research Scientist
  - 30+ years of analog and digital design
    - PHENIX Hadron Blind, Resistive Plate Chamber, & Muon Piston Chamber Detectors
    - MiniBoone/MicroBoone digitial electronics
  - Recipient of IEEE 2014 Computer Applications in Nuclear and Plasma Sciences Award

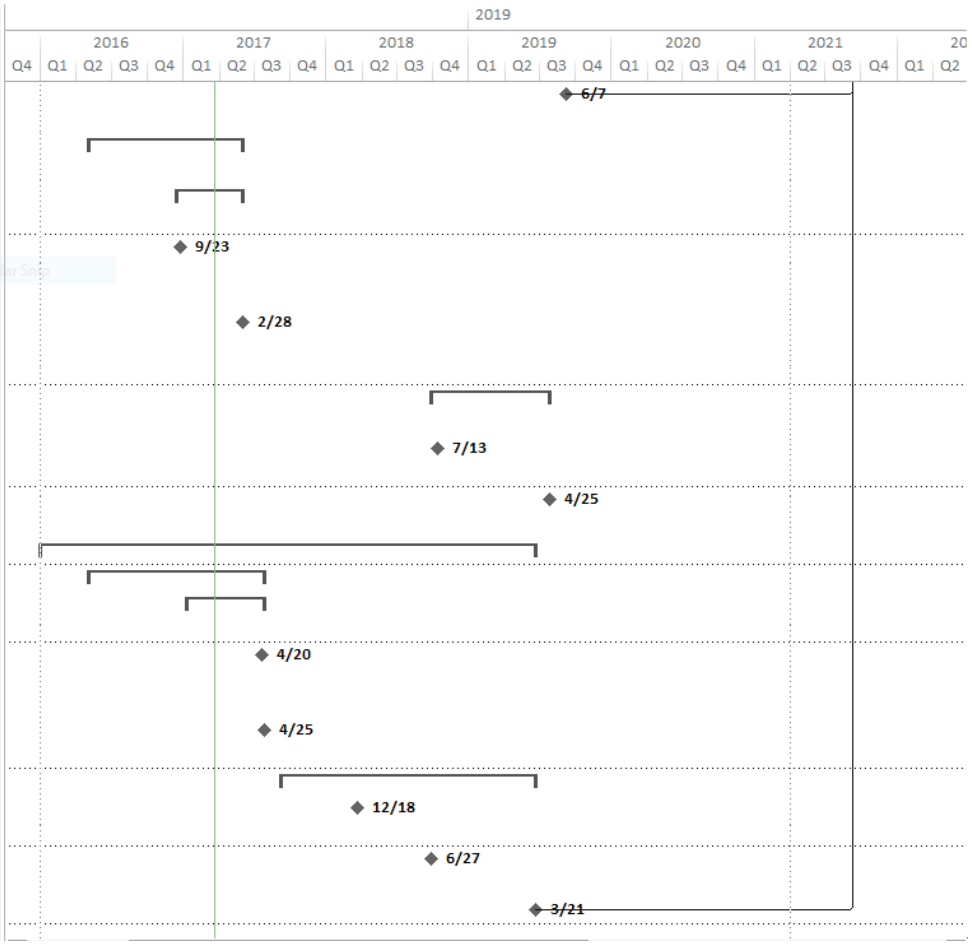
WBS 1.6: Schedule Drivers-I

WBS	Task Name	Start	Finish
1.5.1	**CalElectronics Management**	**Thu 10/1/15**	**Thu 12/31/20**
1.10.04.07.12	Complete Commissioning	Wed 6/30/21	Wed 6/30/21
1.1.5	Receive CD-1 Authorization	Wed 11/29/17	Wed 11/29/17
1.5.1.7	Receive DOE CD-1	Wed 11/29/17	Wed 11/29/17
1.1.9	Receive CD2/CD3 Authorization	Wed 6/27/18	Wed 6/27/18
1.5.1.8	Receive DOE CD-2/3	Wed 6/27/18	Wed 6/27/18
1.5.2	**Calorimeter Optical sensors**	**Thu 10/1/15**	**Tue 5/14/19**
1.5.2.2	**EMCal Sensor Procurement**	**Tue 12/15/15**	**Tue 5/14/19**
	Order EMCal Production Optical Sensors	Wed 11/29/17	Wed 11/29/17
	EMCal Optical Sensor Order Complete	Wed 7/25/18	Wed 7/25/18
1.5.2.4	**HCal Sensor Procurement**	**Fri 11/13/15**	**Thu 3/7/19**
	Order HCal Production Optical Sensors	Wed 6/27/18	Wed 6/27/18
	HCal Production Optical Sensor Order Complete	Thu 12/20/18	Thu 12/20/18
1.5.3	**Calorimeter on detector electronics**	**Thu 10/1/15**	**Fri 6/7/19**
1.5.3.2	**EMCal on detector electronics prototype**	**Mon 1/25/16**	**Tue 3/7/17**
1.5.3.2.2	**EMCal on detector prototype electronics preproduction prototype**	**Fri 9/2/16**	**Tue 3/7/17**
	EMCal On-Detector Preproduction Electronics Design and Safety Review Complete	Fri 9/16/16	Fri 9/16/16
1.5.3.2.2.6	EMCal On-Detector Proproduction Prototypes Electronics Testing Complete	Tue 3/7/17	Tue 3/7/17
1.5.3.3	**EMCal on detector electronics production**	**Wed 6/27/18**	**Fri 6/7/19**
	EMCal ON-Detector Electronics Production Design Review Complete	Wed 6/27/18	Wed 6/27/18



WBS 1.6: Schedule Drivers-II

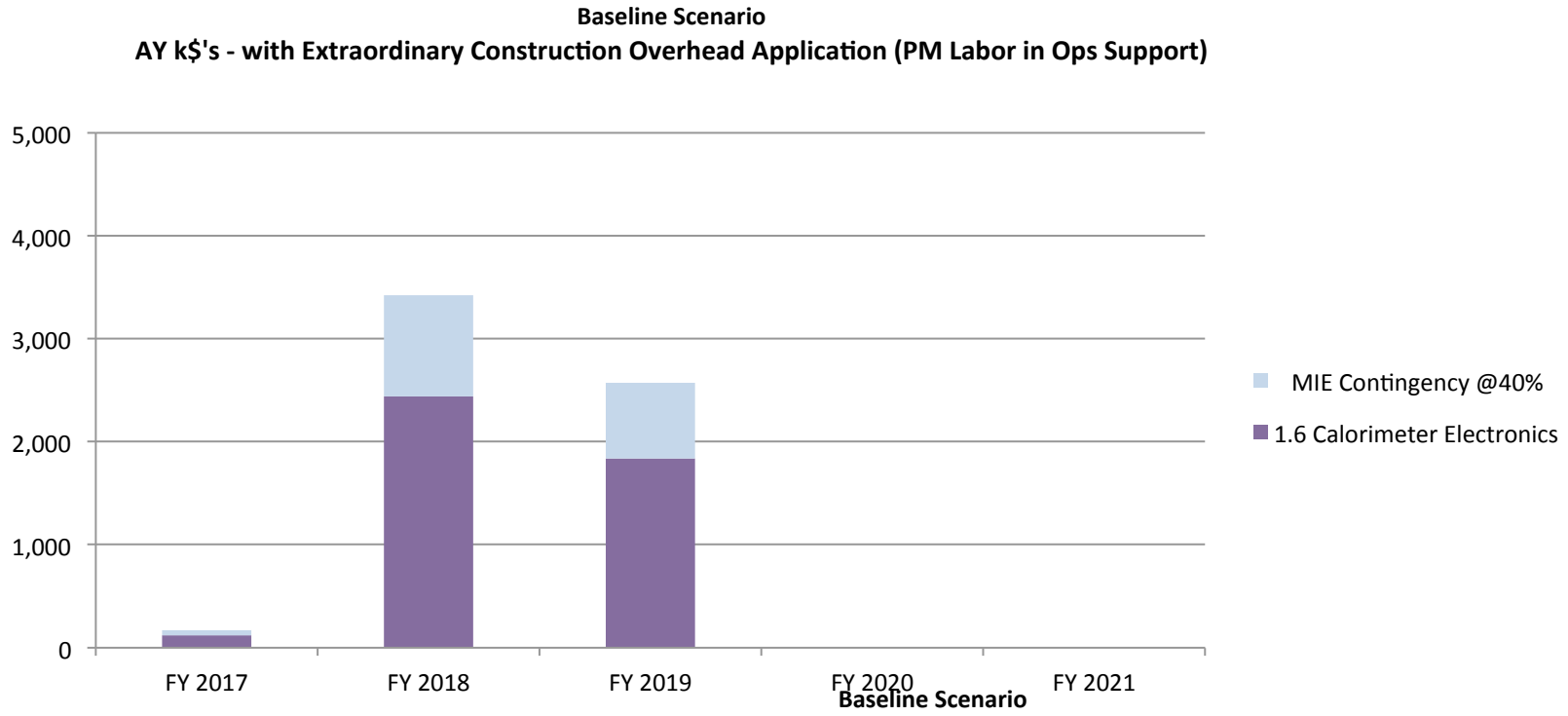
WBS	Task Name	Start	Finish
1.5.3.3.6	EMCal On-Detector Production Electronics Complete	Fri 6/7/19	Fri 6/7/19
1.5.3.5	**HCal on detector electronics prototyping**	**Mon 2/1/16**	**Tue 2/28/17**
1.5.3.5.2	**HCal on detector electronics preproduction prototype**	**Mon 9/12/16**	**Tue 2/28/17**
	HCal Electronics Preproduction Design and Safty Review Complete	Fri 9/23/16	Fri 9/23/16
1.5.3.5.2.7	HCal on-detector electronics preproduction prototype complete	Tue 2/28/17	Tue 2/28/17
1.5.3.6	**HCal on detector electronics production**	**Wed 6/27/18**	**Thu 4/25/19**
	HCal On-Detector Electronics Production Review Complete	Fri 7/13/18	Fri 7/13/18
1.5.3.6.6	HCal On-Detector Production Electronics Complete	Thu 4/25/19	Thu 4/25/19
1.5.4	**Calorimeter digitizer system**	**Thu 10/1/15**	**Thu 3/21/19**
1.5.4.2	**Calorimeter Digitizer prototype**	**Mon 2/1/16**	**Tue 4/25/17**
1.5.4.2.2	**Calorimeter digitizer preproduction prototype**	**Mon 10/10/16**	**Tue 4/25/17**
	Calorimeter Preproduction Digitizer Design and Safty Review Complete	Thu 4/20/17	Thu 4/20/17
	Calorimeter digitizer electronics R&D complete	Tue 4/25/17	Tue 4/25/17
1.5.4.3	**Calorimeter digitizer production**	**Thu 6/8/17**	**Thu 3/21/19**
	Calorimeter Production Electronics Design and Safety Review Complete	Mon 12/18/17	Mon 12/18/17
	Calorimeter Digitizer Production Electronics Construction Starts	Wed 6/27/18	Wed 6/27/18
1.5.4.3.5	Complete Calorimeter Electronics	Thu 3/21/19	Thu 3/21/19



WBS 1.6: Budget

- SiPMs
  - EMCal: $920K
  - HCal: $132K
- EMCal Analog Electronics:
  - Components: $1.3M
  - Assembly: $134K
- HCal Analog Electronics
  - Components: $175K
  - Assembly: $105K
- Digitizer Electronics
  - Components: $1.1M
  - Assembly: $425K

WBS 1.6: Budget



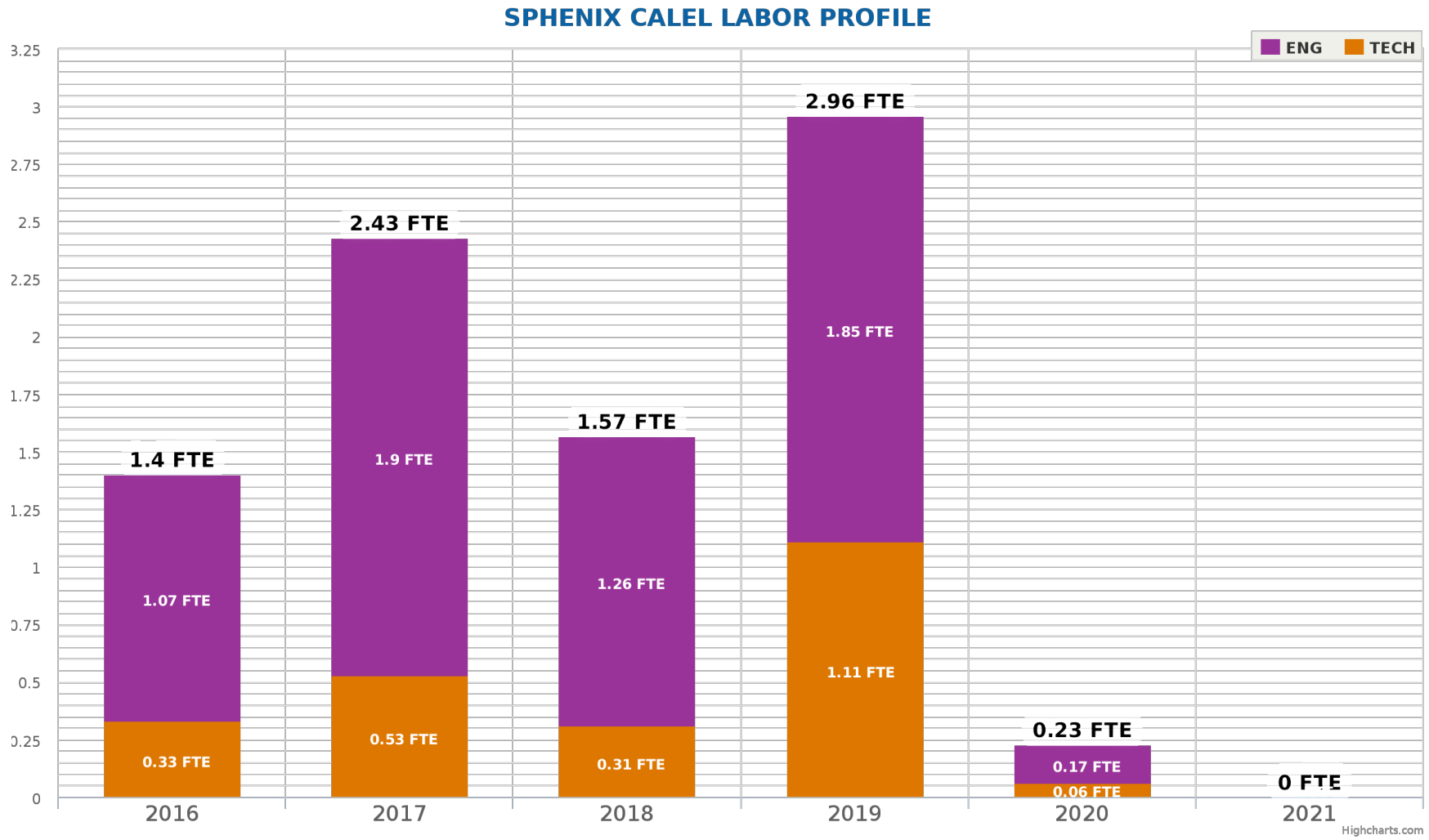
Baseline Scenario

AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)

WBS	SYSTEM	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
1.6	**Calorimeter Electronics**	120	2,444	1,837	0	0	4,401
	MIE Contingency @40%	**48**	**977**	**735**	**0**	**0**	**1,760**
	MIE Total	168	3421	2572	0	0	6161

WBS	**SYSTEM**	**Baseline**	**Contingency(40%)**	**Total**

WBS 1.6: Labor Profile



WBS 1.6: Status

- EMCal/HCal Analog Prototype V0: Test Beam Evaluation in Feb 2014 (Generic R&D)
- EMCal/HCal Analog Prototype V1: Test Beam Evaluation in April 2016 (Generic R&D)
- EMCal/HCal Analog Prototype V2: Test Beam Evaluation Scheduled Jan 2017 (Generic R&D)
- Digitizer Prototype V1 testing to start Jan 2017 (Generic R&D)
- EMCal/HCal Analog preproduction prototype FY2018 (OPC)

WBS 1.6 Dictionary Example

1. Project Title:	2. Date:	3: Person Responsible
SPHENIX	3/17/2015	E. Mannel

4. WBS Element Code	5. WBS Element Title
1.07.01	Calorimeter Electronics Oversight and Management

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

Labor cost only, no material. Labor based on subsystem engineer with 50% of time spent on project management.

TECHNICAL SCOPE:

Level 2 Engineer overseeing and managing the design, prototyping and production of EMCal and HCal front end and back end electronics. Responsibilities include budgeting, preparation of reports and presentations.

WORK STATEMENT:

Provide management and oversight of the design, prototyping and production of the electronics for the sPHENIX EMCal and HCal electronics. Specific tasks include:

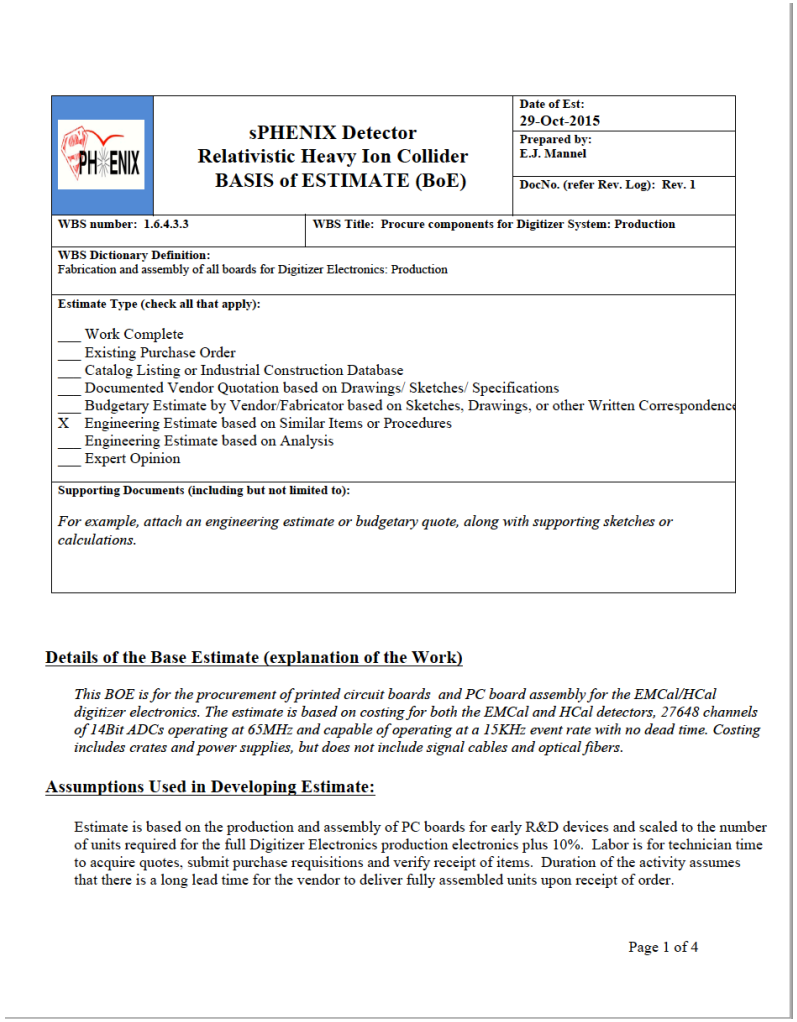
1. Produce and monitor overall schedule for all aspects of the design, prototyping and production of the sPHENIX EMCal and HCal electronics to make sure that all milestones are met on schedule.
2. Provide overall management of procurement activities and monitoring of expenditures for the sPHENIX EMCal and HCal electronics
3. Work with scientific and engineering staff to produce all technical design documents. Review documentation to make sure that the design will achieve the performance needed to meet the scientific goals of sPHENIX.
4. Participate in project reviews:
   a. Assist with producing review documents.
   b. Make presentations at project reviews when requested.
5. Organize and schedule technical design, prototype performance and production readiness reviews for the sPHENIX EMCal and HCal electronics.

Page 1 of 28

- WBS dictionary has been developed to level 4; 1.05.xxx.yyy
- Includes:
  - Cost Content
  - Technical Scope
  - Work Statement
- It is a work in progress
  - Currently ~34 tasks
  - 28 pages in length

WBS 1.6: Basis of Estimate

- Defines
  - Scope of the Estimate
  - Pricing assumptions
  - Labor Estimates for planning purposes. Only Proj Mangt labor is incl in MIE
  - Material
  - Risk Level
- Currently created for “high cost” Items



	sPHENIX Detector **Relativistic Heavy Ion Collider** **BASIS of ESTIMATE (BoE)**	**Date of Est:** 29-Oct-2015 **Prepared by:** E.J. Mannel **DocNo. (refer Rev. Log): Rev. 1**

WBS number: 1.6.4.3.3 | **WBS Title: Procure components for Digitizer System: Production**

WBS Dictionary Definition:
Fabrication and assembly of all boards for Digitizer Electronics: Production

Estimate Type (check all that apply):

___ Work Complete
___ Existing Purchase Order
___ Catalog Listing or Industrial Construction Database
___ Documented Vendor Quotation based on Drawings/ Sketches/ Specifications
___ Budgetary Estimate by Vendor/Fabricator based on Sketches, Drawings, or other Written Correspondence
X Engineering Estimate based on Similar Items or Procedures
___ Engineering Estimate based on Analysis
___ Expert Opinion

Supporting Documents (including but not limited to):

For example, attach an engineering estimate or budgetary quote, along with supporting sketches or calculations.

Details of the Base Estimate (explanation of the Work)

This BOE is for the procurement of printed circuit boards and PC board assembly for the EMCal/HCal digitizer electronics. The estimate is based on costing for both the EMCal and HCal detectors, 27648 channels of 14Bit ADCs operating at 65MHz and capable of operating at a 15KHz event rate with no dead time. Costing includes crates and power supplies, but does not include signal cables and optical fibers.

Assumptions Used in Developing Estimate:

Estimate is based on the production and assembly of PC boards for early R&D devices and scaled to the number of units required for the full Digitizer Electronics production electronics plus 10%. Labor is for technician time to acquire quotes, submit purchase requisitions and verify receipt of items. Duration of the activity assumes that there is a long lead time for the vendor to deliver fully assembled units upon receipt of order.

Page 1 of 4

WBS 1.6: Basis of Estimate-II

Cost Summary

	Material [$]	Designer [d]	Engineer [d]	Tech [d]	Physicist [d]	Student [d]
Subsystem:	**425,000**	x	x	x	x	x

Contingency

M&S Contingency Rules Applied

- **M5**
- *Pricing based on costs for producing R&D devices of similar design and scaled for large quantities. All components are catalog items.*

Labor Contingency Rules Applied

-
- *Labor is for producing order specification documents, tracking order and verifying delivery of components*

Comments:

Provide any additional details that may affect scope, effort, materials, estimating technique, sketches, calculations, etc.

Risk Analysis: – (To Be Completed by Subsystem Manager)

- Schedule Risk – (see Impact Assessment Matrix and Risk Classification Matrix)
  - Potential problem:
  - Mitigation:
- Cost Risk – (see Impact Assessment Matrix and Risk Classification Matrix)
  - Potential problem:
  - Mitigation:
- Technical/Scope Risk – (see Impact Assessment Matrix and Risk Classification Matrix)
  - Potential problem:
  - Mitigation:

Page 2 of 4

Digitizers System

Digitizer Board Fabrication	200.00	428	$85,600
Digitizer Board Assembly	600.00	428	$256,800
Controller Board Fabrication	200.00	28	$5,600
Controller Board Assembly	600.00	28	$16,800
XMIT Board Fabrication	200.00	28	$5,600
XMIT Board Assembly	600.00	28	$16,800

Cost by WBS Line:

1.6.4.3.3	$426,000.00

Page 4 of 4

WBS 1.6: Risk Analysis

Risk	Rank	Mitigation Plan
SiPM Procurement Schedule	Low	Investigate alternative vendors. Early procurement
SiPM Neutron Damage/ Life Time	Moderate	Continue irradiation studies Evaluate alternative SiPM devices
EMCal Cooling	Moderate	Early design work ½ Sector prototype evaluation
Noise and Cross Talk	Low	Detailed grounding plan Early prototype evaluation Detailed design reviews
Interior Cable Routing-EMCal	Low	Early design work ½ Sector prototype evaluation

WBS 1.6: Issues and Concerns

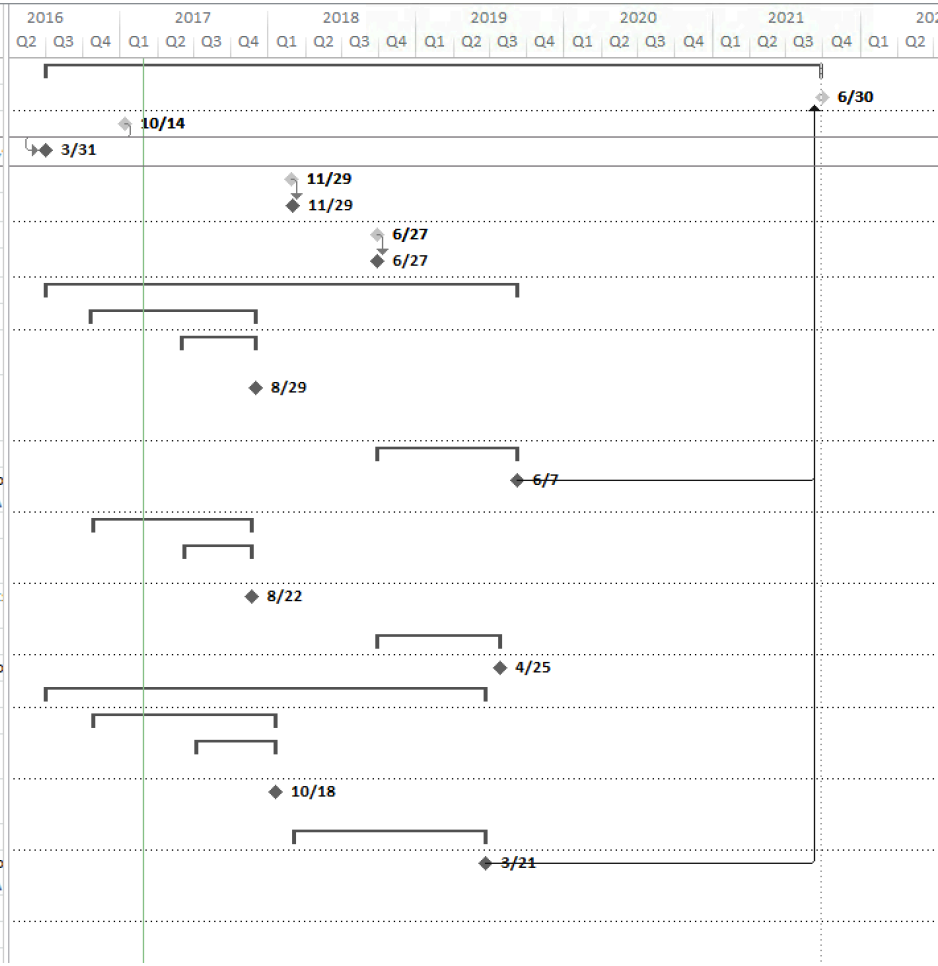
- Neutron radiation damage: Continuing studies in progress
- Gain stability: Plan developed and being tested
- Radiation tolerance of devices: Will qualify all devices in "high" radiation areas.
- Signal Integrity (e.g.: cross talk, noise levels): On going studies in progress
- Ground Plan: Preliminary plan being developed
- Cable Routing: Using mockups to finalize plan
- Prototyping: Multiple tests scheduled: Lab, Test Beam…
- Labor: Core group in place, BNL/Columbia, for design and fabrication, but will need to work with collaborators to finalize production testing stage.

BACKUP SLIDES

Milestones

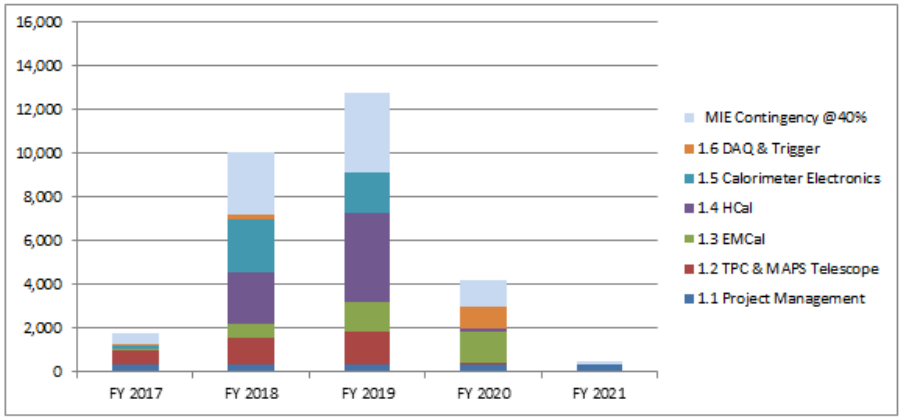
GANTT CHART

	WBS	Task Name	Predecessors	Successors
1	**1.5.1**	**CalElectronics Management**		
3	1.10.04.07.12	Complete Commissioning	2,4,5,6,100,197	
7	1.1.2	Receive DOE CD-0 Authorization		8FS-137 days
8	1.5.1.6	SiPM choice confirmed by beam test	C:\Users\phoncs\Docum	15,32,52,102,156,2,
9	1.1.5	Receive CD-1 Authorization		10
10	1.5.1.7	Receive DOE CD-1	C:\Users\phoncs\Docum	28
11	1.1.9	Receive CD2/CD3 Authorization		12
12	1.5.1.8	Receive DOE CD-2/3	C:\Users\phoncs\Docum	47,94,146,194
50	**1.5.3**	**Calorimeter on detector electronics**		
79	**1.5.3.2**	**EMCal on detector electronics prototype**		
85	**1.5.3.2.2**	**EMCal on detector prototype electronics preproduction prototype**		
92	1.5.3.2.2.6	EMCal on-detector electronics Preproduction Prototype Testing Complete	91	70
93	**1.5.3.3**	**EMCal on detector electronics production**		
100	1.5.3.3.6	All On Detector Electronics Complete	98	C:\Users\phoncs\Do & Installation.mpp\
126	**1.5.3.5**	**HCal on detector electronics prototyping**		
134	**1.5.3.5.2**	**HCal on detector electronics preproduction prototype**		
143	1.5.3.5.2.7	Hcal on Detector electronics preproduction prototype complete	142	118,C:\Users\phonc
145	**1.5.3.6**	**HCal on detector electronics production**		
152	1.5.3.6.6	Hcal on-detector electronics complete	151,147	C:\Users\phoncs\Do
154	**1.5.4**	**Calorimeter digitizer system**		
178	**1.5.4.2**	**Calorimeter Digitizer prototype**		
184	**1.5.4.2.2**	**Calorimeter digitizer preproduction prototype**		
191		Calorimeter digitizer electronics R&D complete	190	193
192	**1.5.4.3**	**Calorimeter digitizer production**		
197	1.5.4.3.5	Complete Calorimeter Electronics	196FS+20 days	C:\Users\phoncs\Do & Installation.mpp\



E) Current Status of Cost Estimate

Category A: sPHENIX MIE Project Scope - Nov 2016



Baseline Scenario

AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)

WBS	SYSTEM	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
1.1	Project Management	370	370	370	370	370	1,850
1.2	TPC & MAPS Telescope	582	1,172	1,449	59		3,262
1.3	EMCal	127	647	1,401	1,383	0	3,557
1.4	HCal	0	2,353	4,044	166	0	6,562
1.5	Calorimeter Electronics	120	2,444	1,837	0	0	4,401
1.6	DAQ & Trigger	80	190	29	1,026	0	1,325
	Baseline Total	1,279	7,175	9,130	3,004	370	20,957
	MIE Contingency @40%	511	2,870	3,652	1,201	148	8,383
	MIE Total	1790	10045	12781	4205	518	29339

WBS	SYSTEM	Baseline	Contingency(40%)	Total	
1.1	Project Management	1,850	740	2,590	
1.2	TPC and MAPS Telescope	3,262	1305	4,567	Revised Tracker Review - Sept 2016
1.3	EMCal	3,557	1423	4,980	
1.4	HCal	6,562	2625	9,187	
1.5	Calorimeter Electronics	4,401	1760	6,161	
1.6	DAQ & Trigger	1,325	530	1,855	
	MIE Totals	20,957	8,383	29,339	

Required Number of Production Components

- Optical Sensors: 113664
  - EMCAL: 98304
  - HCal: 15360
- Preamp Boards*: 4352
  - EMCal: 1536
  - HCal: 3072
- Interface Boards*:
  - EMCal: 64
  - HCal: 128
- Controllers:
  - EMCal: 8
  - HCal: 16
- Digitizer Boards: 432
  - EMCal: 384
  - HCal: 48
- XMIT Boards:108
  - EMCal: 96
  - HCal: 12
- Digitizer Controllers/Clock Masters: 28
  - EMCal: 24
  - HCal: 4
- Crates: 28
  - EMCal: 24
  - HCal: 4

* Different layout for EMCal/HCal

E) Cost Estimates

- Based on:
  - Number of modules required in reference design.
  - Cost of R&D modules scaled to production quantities where possible
  - Cost of similar or past produced modules if there is not yet an R&D version.
  - Budgetary estimates for large cost items: SiPMs, FPGAs, ADCs, Signal Cables…
  - Fabrication and assembly commercially done, only final assembly done in house.
  - Includes Q/A testing
  - Continuing to refine as designs become more detailed.

H) Path to CD-1

- Updates to:
  - 1-Feb-2017: Project File; E. Mannel
  - 1-Feb-2017: WBS Dictionary; E. Mannel
  - 1-Feb-2017: Risk Analysis; E. Mannel
  - 1-Mar-2017: Bottoms up cost estimate with budgetary quotes were appropriate for most recent design. S. Stoll, C. Chi, S. Boose
  - 1-Mar-2017: Basis of Estimate and Cost Sheets; E. Mannel, S. Stoll, C. Chi, S. Boose
- Ongoing: Update design documentation
  - Technical specifications; E. Mannel, S. Boose
  - Design documents; E. Mannel, S. Boose, C. Chi
- Prepare CD-1 documentation as required; E. Mannel, S. Boose, C. Chi, C. Aidala
  - BNL Internal Review: April 2017
  - DOE Review: June 1